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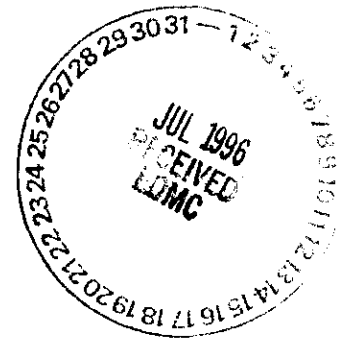
Department of Energy

Richland Operations Office
P.O. Box 550
Richland, Washington 99352

JUN 13 1996

Mr. Steve M. Alexander
Perimeter Areas Section Manager
Nuclear Waste Program
State of Washington
Department of Ecology
1315 W. Fourth Avenue
Kennewick, Washington 99336-6018

Mr. Douglas R. Sherwood
Hanford Project Manager
U.S. Environmental Protection Agency
712 Swift Boulevard, Suite 5
Richland, Washington 99352-0539



Dear Messrs. Alexander and Sherwood:

TRANSMITTAL OF APPENDIX A DRAFT NUMERICAL MODELING MATERIAL

Attached is the subject information requested by the U.S. Environmental Protection Agency (EPA) and the State of Washington, Department of Ecology (Ecology), at the Unit Manager's Meeting on May 8, 1996. The information was requested by EPA for independent review by the U.S. Geological Survey and to provide EPA and Ecology with the background information needed to provide support to the U.S. Department of Energy, Richland Operations Office, to proceed with the procurement and associated construction activities related to the remedial actions associated with 100-HR-3 and 100-KR-4 Record of Decision.

If you have any questions, please contact me at 373-9631.

Sincerely,

Arlene C. Tortoso, Project Manager
Groundwater Project

GWP:ACT

Attachment

cc w/o attach:
L. E. Gadbois, EPA
G. C. Henckel, BHI
A. J. Knepp, BHI
W. W. Soper, Ecology

cc w/attach:
S. Balone, EM-442

5/9/96 DRAFT

APPENDIX A NUMERICAL MODELING

1.0 Development of Numerical Groundwater Models

To support the interim action design process, numerical groundwater models were developed for each of the three areas of the interim action; one each of the 100-H and 100-D Areas of the 100-HR-3 Operable Unit (OU), and one of the 100-KR-4 OU. The numerical models were used to help determine the placement of new wells, and the use of existing wells to support the interim action. The numerical modeling was also used to estimate extraction and injection rates for interim action design purposes.

Numerical modeling was performed using the Micro-FemTM finite element program package. This package includes the preprocessing mesh generating programs, the calculation module, and postprocessing programs. The mesh generating program allows the user to construct irregularly shaped and variably spaced finite element triangular meshes. This feature allows for high resolution of the finite element mesh near pumping or injection centers. The calculation module supports either transient or steady-state solution. The postprocessing program enables the user to export the results of the calculations for presentation. The Micro-FemTM package was chosen for the numerical modeling because of the finite element mesh generating capability, the solution capability, and the output capability.

2.0 Model Boundaries

Section 2.1 through 2.3 describe the model boundaries for each of the three areas.

2.1 100-H Area

Figure 1 shows the model grid used for the 100-HR-3 H Area interim action design modeling. Note the high density of points in the areas of greatest interest. The high density grid area is enlarged and depicted in Figure 2. The Columbia River formed the eastern model boundary for the 100-H area. Naturally occurring hydrologic boundaries do not exist in the other directions. Consequently, the remaining three model boundaries were located far enough from the area of interest that hydraulic changes caused by withdrawal and injection would not be evident at the boundary. To the west, the boundary was located parallel to prevailing water table contour lines. To the north and south, the boundaries were located perpendicular to the prevailing water table contour lines (i.e., parallel to the hydraulic gradient). To the west, where the water table remains fairly constant throughout the year, the boundary was assumed to be constant head. Because groundwater flow was assumed to occur parallel to and not across the north and south boundaries, these boundaries were assigned to be no flow. The Hanford/Ringold Formation

5/9/96 DRAFT

contact served as the bottom of the model. The model only considered flow through the aquifer contained within the Hanford formation.

The river and aquifer were assumed to be connected vertically. If the hydraulic head of the groundwater exceeded the river stage elevation, flow exited the model. If the river stage elevation exceeded the hydraulic head of the groundwater, flow entered the model. The river stage was assumed to be constant. Attempting to incorporate the stage trends and fluctuations of the Columbia River was considered too complex for the purpose of this modeling. For similar reasons, bank storage effects were simply assumed to be included in the vertical resistance term between the groundwater and river nodes.

2.2 100-D Area

Figure 3 shows the model grid used for the 100-D Area design modeling. The Columbia River formed the northwest model boundary for the 100-D area. All other model boundaries were constant head due to the hydrogeology of the area. A flow divide occurs through the 100-D Area. Recharge from Gable Mountain, Gable Butte and the gap between the two and recharge from Umtanum Ridge discharges into the Columbia River at 100-D Area and all across the horn. Consequently, recharge appears to occur almost directly south of the two 100-D Area reactor buildings. The constant head values were initially interpreted from the June 1995 water table map in the RCRA Annual Report (DOE-RL, 1995).

The river and the aquifer were assumed to be connected vertically. If the hydraulic head of the groundwater exceeded the river stage elevation, flow exited the model. If the river stage elevation exceeded the hydraulic head of the groundwater, flow entered the model. The rate at which the flow entered or exited the model depended on the hydraulic head difference and the vertical resistance between the aquifer and the river. The river stage was assumed to be constant. Attempting to incorporate the stage trends and fluctuations of the Columbia River was considered too complex for the purpose of this modeling. For similar reasons, bank storage effects were simply assumed to be included in the vertical resistance term between the groundwater and the river.

2.3 100-KR-4

Figure 4 shows the model grid used for the 100-KR-4 OU interim action design modeling. The Columbia River formed the northern model boundary for the 100-KR-4 OU. Naturally occurring hydrologic boundaries do not exist in the other directions. Consequently, the remaining three model boundaries were artificially constructed and located away from the extraction and injection areas to minimize boundary influences in those areas. The boundaries perpendicular to the river were designated no flow because the prevailing flow lines are essentially perpendicular to the river. The inland boundary roughly parallel to the river was constant head.

5/9/96 DRAFT

The river and the aquifer were assumed to be connected vertically. If the hydraulic head of the groundwater exceeded the river stage elevation, flow exited the model. If the river stage elevation exceeded the hydraulic head of the groundwater, flow entered the model. The rate at which the flow entered or exited the model depended on the hydraulic head difference and the vertical resistance between the aquifer and the river. The vertical resistance term is purely empirical and was determined solely through calibration of the model. The river stage was assumed to be constant. Attempting to incorporate the stage trends and fluctuations of the Columbia River was considered to complex for the purpose of this modeling. For similar reasons, bank storage effects were simply assumed to be included in the vertical resistance term between the groundwater and the river.

3.0 Model Input Parameters

The input parameters required for the modeling are the aquifer transmissivity, the hydraulic head at the constant head boundaries, and the saturated thickness of the aquifer. Hydraulic gradients for all three areas were variable. A table of parameter values used for modeling each area is provided in Table 1.

3.1 100-H Area

The transmissivity values were based on the saturated thickness of the Hanford formation and measurements of the hydraulic conductivity. Figure 5 shows the distribution of transmissivity used in the model. Note the decrease in transmissivity in the areas north and east of the 183-H Solar Evaporation Basins. The elevation of the Hanford/Ringold Formation contact rises about 3 meters in this area. Consequently, the saturated thickness of the Hanford formation decreases to less than 1 meter. Elsewhere, the saturated thickness ranges between 3 to 5 meters. Previous estimations of aquifer hydraulic conductivity and the results of the Ferris analysis indicate that the average hydraulic conductivity is around 30.48 m/day (100 ft/day), so this value is used in the model. The hydraulic head in the river was estimated from measurements taken at the 100-H river gauge and an assumed river gradient of 0.00023 m/m. The porosity, which was required for the velocity field calculations, was assumed to be 0.15.

To calibrate the model, the boundary conditions were modeled to steady state. The results of the steady state simulation were compared to the average hydraulic heads in the 100-H Area wells measured from January 1994 to August 1995. The only parameter that was varied was the resistance term used to connect the river and the groundwater. Figure 6 shows the results of the model calibration. Where measured data exist, the model and measured contours are generally in good agreement, especially near the river. Away from the river where few wells exist, the contours of the model results and measured data do not coincide as well. The gradient of the

5/9/96 DRAFT

modeled data appears greater than the gradient determined from the water level measurements. As can be seen from the figure, well control only exists in a small area compared to the model grid.

3.2 100-D Area

The Ringold Mud Unit forms the bottom of the unconfined aquifer at 100-D. Most of the unconfined aquifer is contained within the Ringold Gravel Unit E. The geologic information available indicates that the unconfined aquifer thickness is fairly uniform, so the transmissivity was uniform throughout most of the model. The hydraulic conductivity of the Ringold Gravel Unit E was 15 m/d (49 ft/d) and the saturated thickness was 5 m (16 ft). In two spots, near Well D8-55 and Well D5-17, the aquifer exists in both Hanford formation and Ringold Gravel Unit E. The hydraulic conductivity of the Hanford formation was 170 m/d (560 ft/d). In these two spots, the hydraulic conductivity in the model was the weighted average of the hydraulic conductivity of the Ringold Gravel Unit E and the Hanford formation. Figure 7 shows the spatial distribution of transmissivity values used in the model. The porosity, which was required for the velocity field calculations, was assumed to be 0.2.

The constant head values were initially interpreted from the June 1995 water table map in the RCRA Annual Report (100-D Ponds). The head values computed under steady state conditions were compared to water level data collected between June 1993 and May 1995. The boundary conditions were then adjusted to calibrate the calculated hydraulic heads to the measured values (Figure 8).

3.3 100-KR-4

The uppermost unconfined aquifer at 100-KR-4 is contained within the Ringold Gravel Unit E, with silty or clayey Paleosol and overbank deposits forming the bottom. Few of the boreholes extend completely through the Ringold Gravel Unit E, but the geologic information available indicates that the unconfined aquifer thickness is fairly uniform. Aquifer hydraulic conductivity data are limited. Testing was performed in wells installed during the limited field investigation (LFI) and in wells installed in 1994. Except for Well K-37, all of those wells were installed near the reactor buildings or retention basins and not in the area of concern (i.e., near the trench). The slug test hydraulic conductivity results from the LFI wells ranged between 5.8 and 44 m/d (19 and 145 ft/d) (DOE-RL, 1994). Slug test results from five of the wells installed in 1994 ranged between 0.98 and 9.8 m/d (3.2 and 32.1 ft/d) (Lindberg, 1995). Constant discharge testing occurred at several wells along the trench, and the geometric mean of the transmissivity determined from those tests was about 90 m²/d (930 ft²/d). The Ferris method analysis (McMahon and Peterson, 1992) performed on data collected in the southern part of the 100-N also indicated an aquifer transmissivity of 90 m²/d. Based on the information available, the

5/9/96 DRAFT

aquifer thickness and hydraulic conductivity were considered uniform throughout the model area. The hydraulic conductivity of the Ringold Gravel Unit E was 7.4 m/d (24 ft/d) and the saturated thickness was 12.2 m (40 ft). Figure 9 shows the spatial distribution of transmissivity values used in the model. The porosity, which was required for the velocity field calculations, was assumed to be 0.2.

The constant head values were initially estimated from the June 1995 water table map in Serkowski, Hartman, and Sweeney (1996). The head values computed under steady state conditions were compared to water level data collected between June 1993 and May 1995. The boundary conditions were then adjusted to calibrate the calculated hydraulic heads to the measured values (Figure 10).

4.0 Modeling Results

For each area, a number of scenarios were developed for simulation. The scenarios were successively modified based on results of iterative model simulations, and in an effort to conceptually optimize pump-and-treat system performance. Drawdown and build-up of the water table caused by the different pump-and-treat configurations were simulated for a five year time span. Streampaths and capture zones were based on the resulting 5 year hydraulic velocity field. Streampaths are the paths followed by the groundwater in the aquifer. Capture zones show the area of the aquifer from which the individual extraction wells draw water. Groundwater contained within or crossing a contour closed around two or more extraction wells becomes trapped. Trapped groundwater is then either captured by one of the extraction wells, or becomes stagnant. Streampaths crossing the river boundary line were terminated at that line and assumed to represent paths of river recharge.

4.1 100-H Area

Modeling of the 100-H area resulted in an interim action design which includes extraction from five wells (i.e., H4-15A, H4-12A, H4-11, H4-7, and H3-2A) and injection of the 100-D and 100-H Areas water at two new injection wells in 100-H Area. The scenario being modeled would involve pumping from all five wells in the early part of the interim action to clean-up water near the river, followed by pumping from only the two upgradient wells to continue to intercept chromium entering the area. Two simulations were performed; the first simulation included all five extraction wells; the second simulation considered only the two upgradient wells, H4-7 and H3-2A. The second simulation assumes that the near-river wells have achieved clean up near the river and are no longer pumping. Extraction wells H4-15A, H4-12A, and H4-11 were pumped at 38 L/min (10 gpm); well H4-7 was pumped at 76 L/min (20 gpm); and well H3-2A was pumped at 151 L/min (40 gpm).

5/9/96 DRAFT

Figure 11 shows the resulting water table contours and capture zones of the first simulation. Almost 50 percent of the influent should be induced from the river within 0.5 to 1 year. The remainder of the streampaths originate at the injection wells. Recirculation between wells H4-11 and H4-12A and the injection wells occurs after about 4.5 years. Recirculation between well H4-15A does not occur for over 14 years, and is not considered to be a factor during the lifespan of this interim action. Based on the streampaths and water table contours, no water is expected to discharge from the groundwater into the river between the near river extraction wells. Both well H4-7 and H3-2A establish recirculation cells with the injection wells. Well H3-2A begins extracting treated water within about 2.5 years. The streampaths terminating at well H4-7 originate at both injection wells. About 55 percent of the influent water pumped from well H4-7 will be diluted by recirculation in about 3 years, and the other portion of the groundwater will not become diluted by recirculation for about 8 years.

Removing the near-river wells from the extraction network does not change the recirculation time greatly for the two upgradient wells, but the streampaths do spread out laterally. In fact, one of the streampaths terminating at well H4-7 does not recirculate with either of the injection wells. The influent dilution percentages of the upgradient extraction wells remain fairly close to those calculated for the preceding simulation. The overall concentration of chromium in the influent water should be higher, because these extraction wells are located where the concentration of chromium is higher. Once recirculation occurs, the chromium concentrations will decrease.

4.2 100-D Area

Modeling of the 100-D area resulted in an interim action design which includes extraction from two wells, D8-53 and D8-54A, and injection of the 100-D water in the 100-H Area. Figure 12 shows the result of pumping D8-53 and D8-54A at 151 L/min (40 gpm). The capture zone of the two wells extends laterally across the entire plume area. Pumping at this rate induces significant recharge. After about 2 years, 33 percent of the influent should come from the river. Table 1 presents the expected chromium concentration at each well. The concentration of the groundwater entering the wells was assumed to be the same as it was where it originated in the aquifer. The concentration of the river recharge was assumed to be 0, and the minimum groundwater concentration outside the 50 µg/L isopleth was assumed to be 25 µg/L. After 5 years, the chromium concentration of the influent water should remain constant for the foreseeable future of the IRM.

4.3 100-KR-4

Modeling of the 100-KR-4 OU resulted in an interim action design which includes extraction from five new extraction wells and one existing well (i.e., well K-20), and injection into three new wells. Two scenarios were run with six extraction wells. In one scenario five new wells placed along the existing road between the river and the trench and an existing well, K-20, were

5/9/96 DRAFT

used as extraction wells. In a second scenario, six new extraction wells are installed, and Well K-20, which is located in a culturally sensitive area, is not used.

The modeling results show that six extraction wells are adequate to prevent chromium in the groundwater at 100-K Area from discharging into the Columbia River (Figure 13). With each extraction well pumped at 95 L/min (25 gpm), the six extraction wells intercept groundwater from along the entire length of the trench. However, under the second scenario groundwater between Well K-20 and the river may go untreated. Chromium concentrations in the extraction wells should remain around 100 µg/L for three to five years. After that, the concentration should decline as more river water, treated groundwater, and groundwater from uncontaminated areas begin entering the extraction wells.

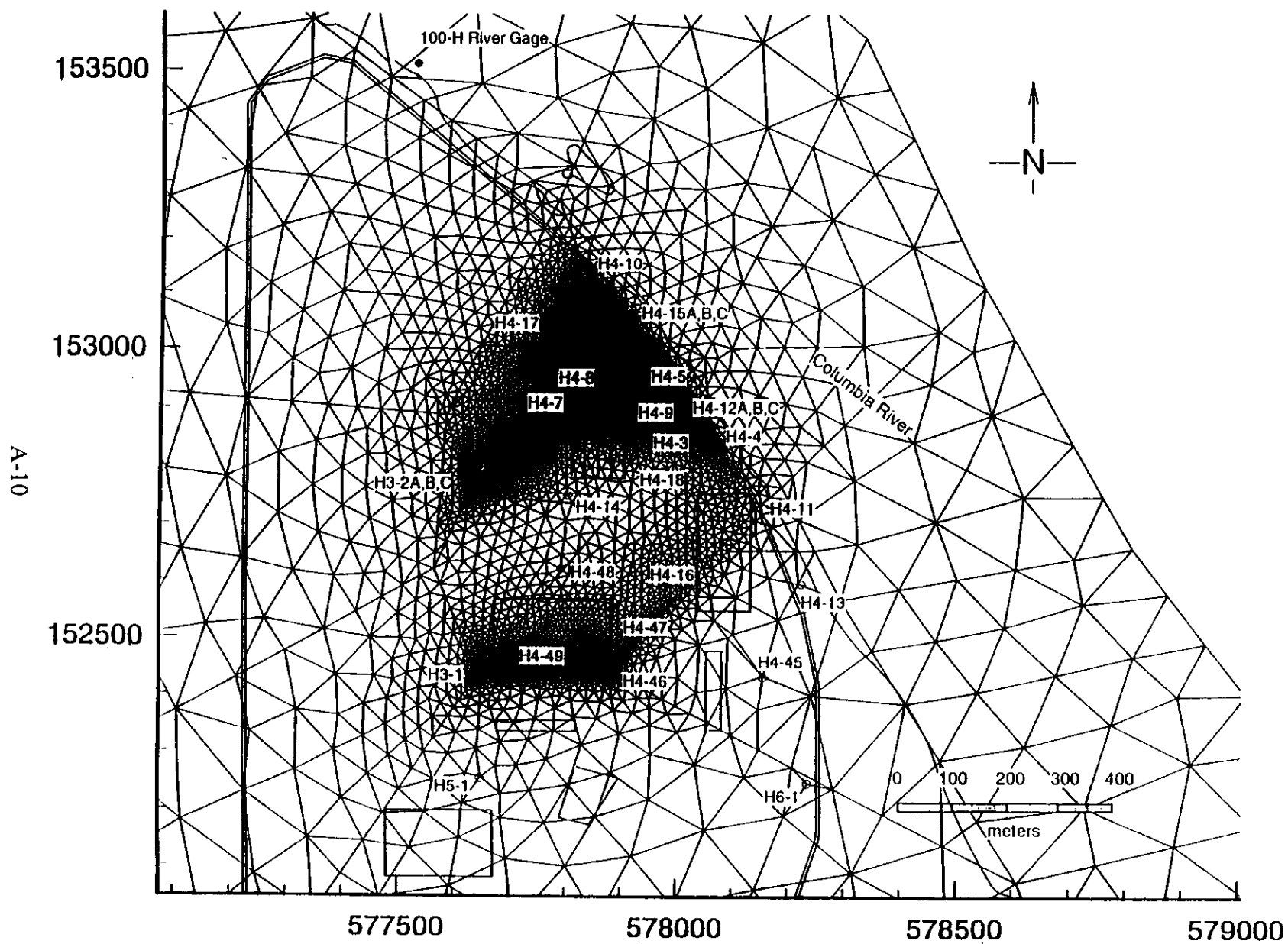
5.0 REFERENCES

- DOE-RL, 1994, *Limited Field Investigation Report for the 100-KR-4 Operable Unit*, DOE/RL-93-79, Rev. 0, U.S. Department of Energy, Richland, Washington.
- DOE-RL, 1995, *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1994*, DOE/RL-94-136, Rev. 0, U.S. Department of Energy, Richland, Washington.
- Lindberg, J. W., 1995, *Hydrogeology of the 100-K Area, Hanford Site, South-Central Washington*, WHC-SD-EN-TI-294, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- McMahon, W.J., and R.E. Peterson, 1992, *Estimating Aquifer Hydraulic Properties Using the Ferris Method, Hanford Site, Washington*, DOE/RL-92-64, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- Serkowski, J. A., M. J. Hartman, and M. D. Sweeney, 1996, *Groundwater Maps of the Hanford Site, June 1995*, WHC-EP-0394-11, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

TABLE 1
MODEL PARAMETERS

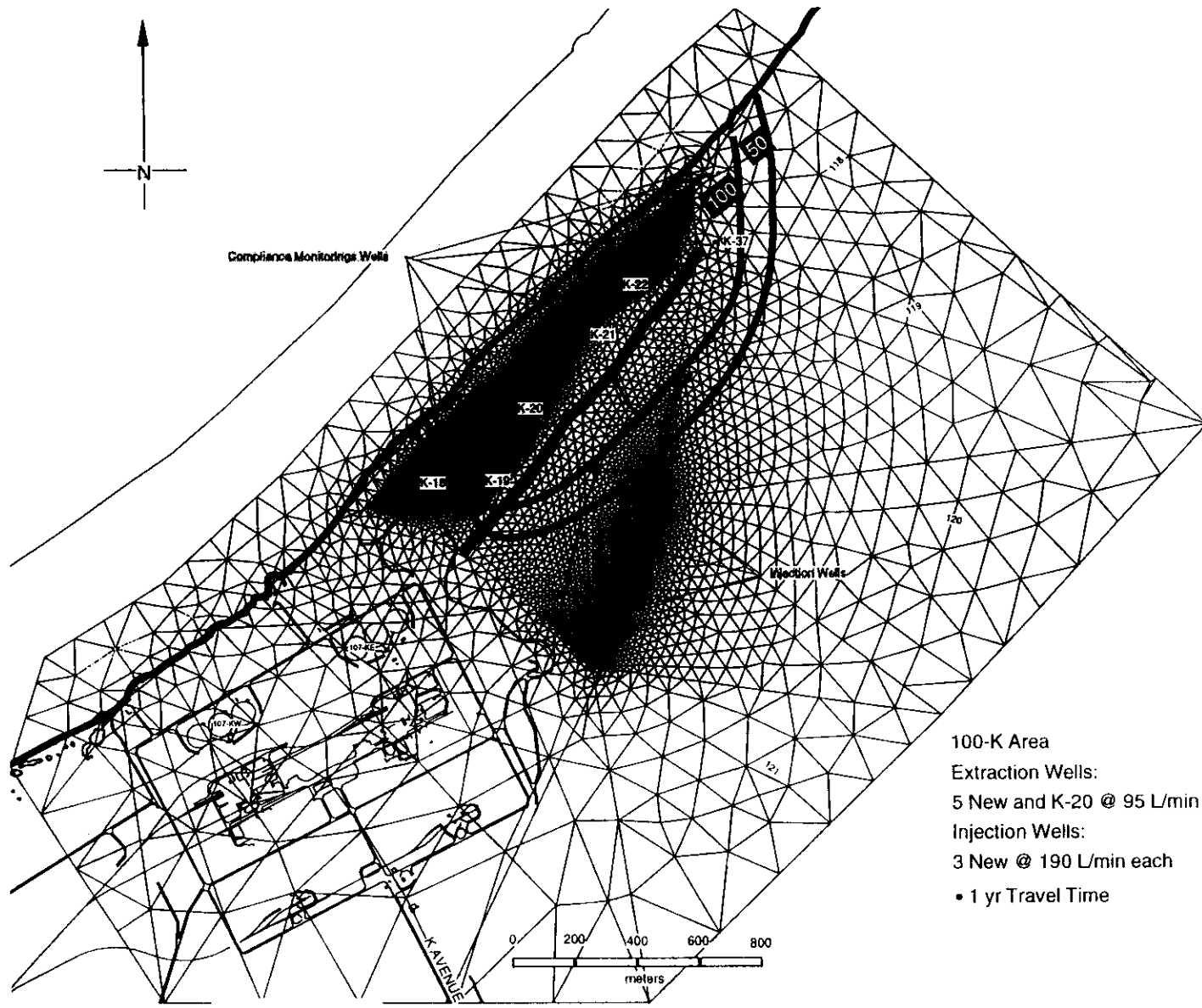
Area	100-H Area	100-D Area	100-KR-4
Model	Micro-Fem TM	Micro-Fem TM	Micro-Fem TM
Boundaries			
Upgradient	Constant Head	Constant Head	Constant Head
Downgradient	Columbia River	Columbia River	Columbia River
Crossgradient	No Flow	Constant Head	No Flow
River/Aquifer Interaction	Head Dependent	Head Dependent	Head Dependent
Aquifer formation	Hanford	Hanford/Ringold	Ringold
HYD. Conductivity	30.48 m/day	170 m/day/15 m/day	7.4 m/day
Gradient	Variable	Variable	Variable
Thickness	1 to 5 m	5 m	12.2 m
Porosity	0.15	0.2	0.2





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Figure 4. 100-KR-4 Model Grid



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Figure 5. H Area Transmissivity Distribution

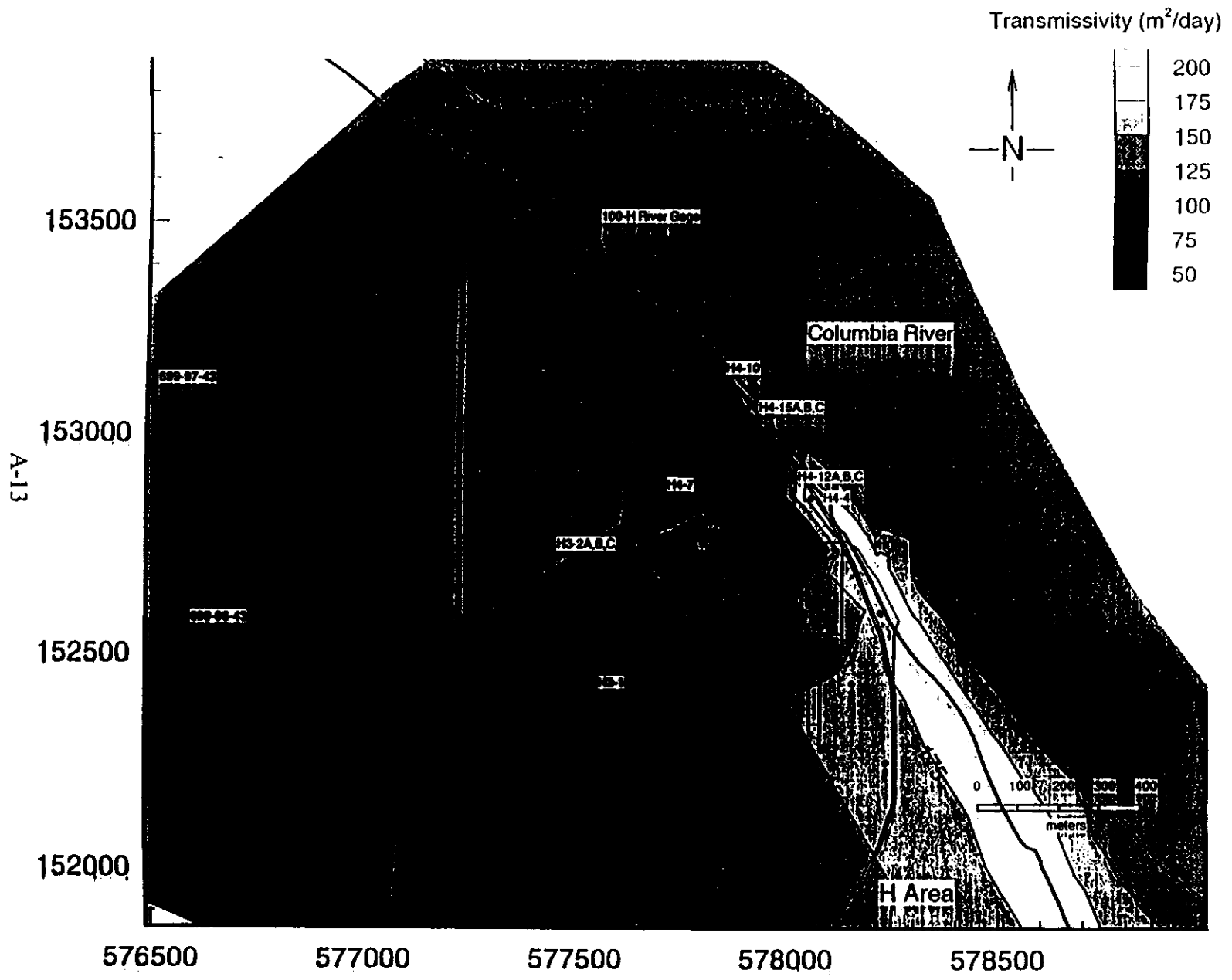


Figure 6. H Area Model Calibration Results

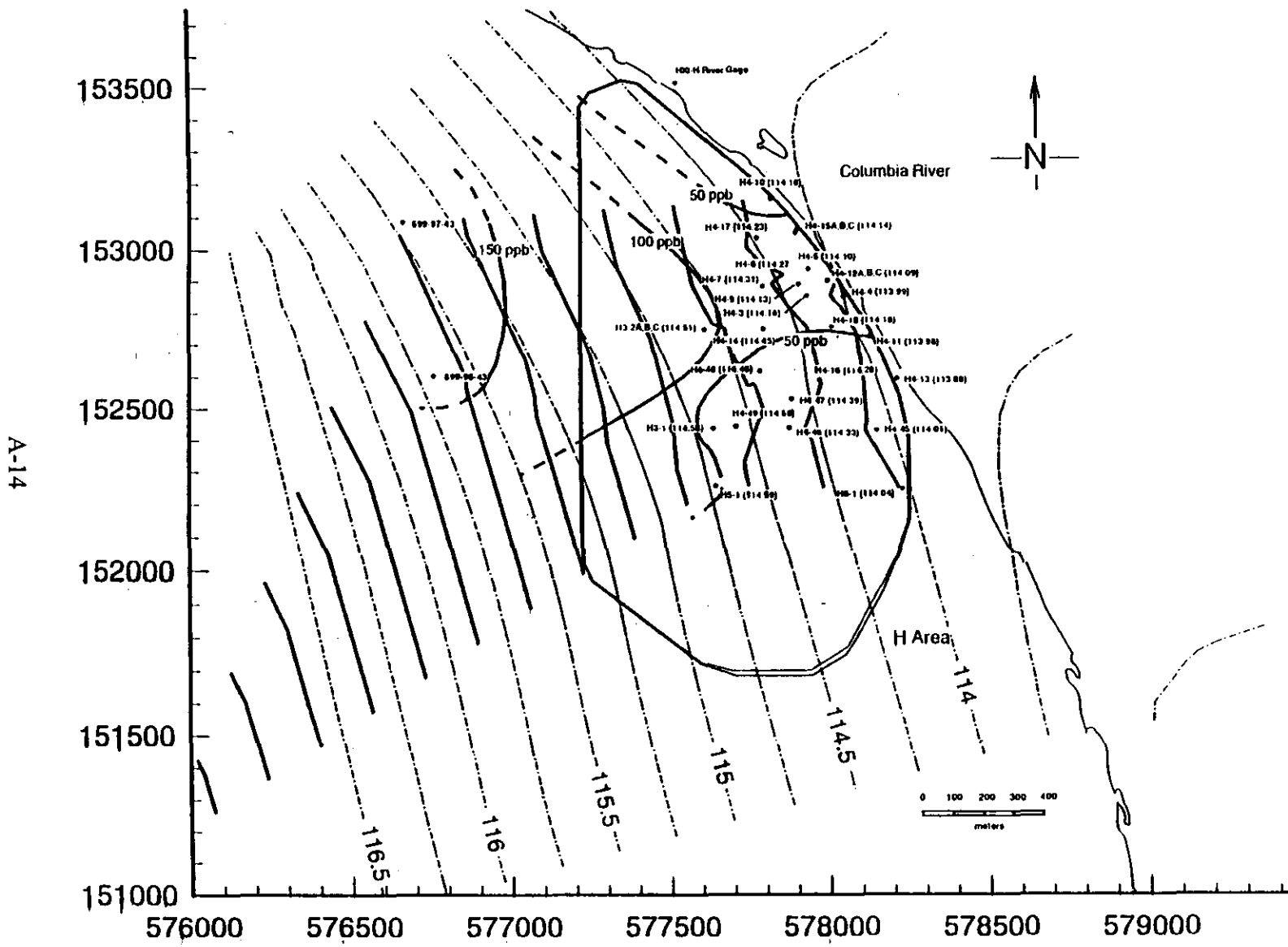


Figure 7. D Area Transmissivity Distribution

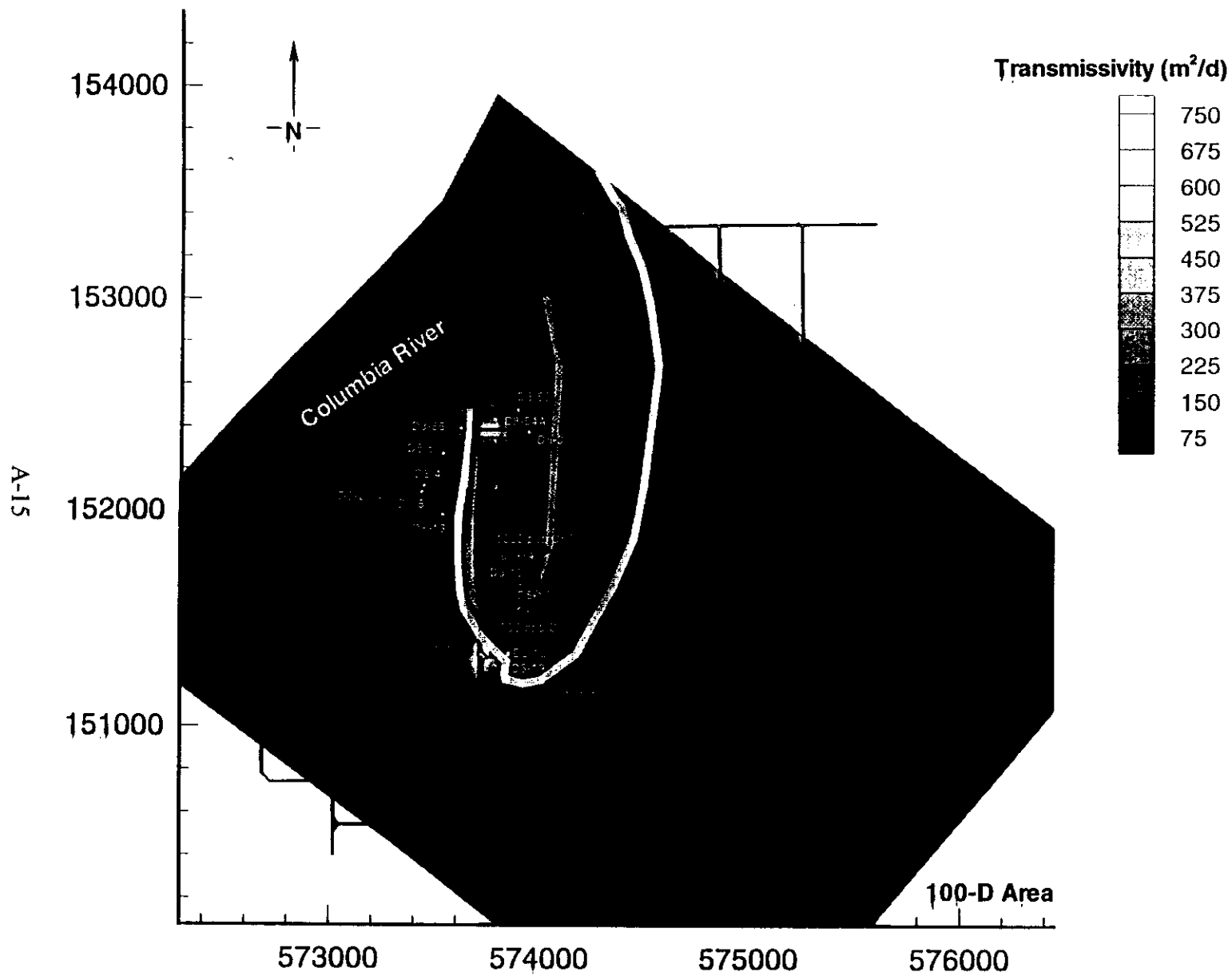


Figure 8. D Area Model Calibration Results

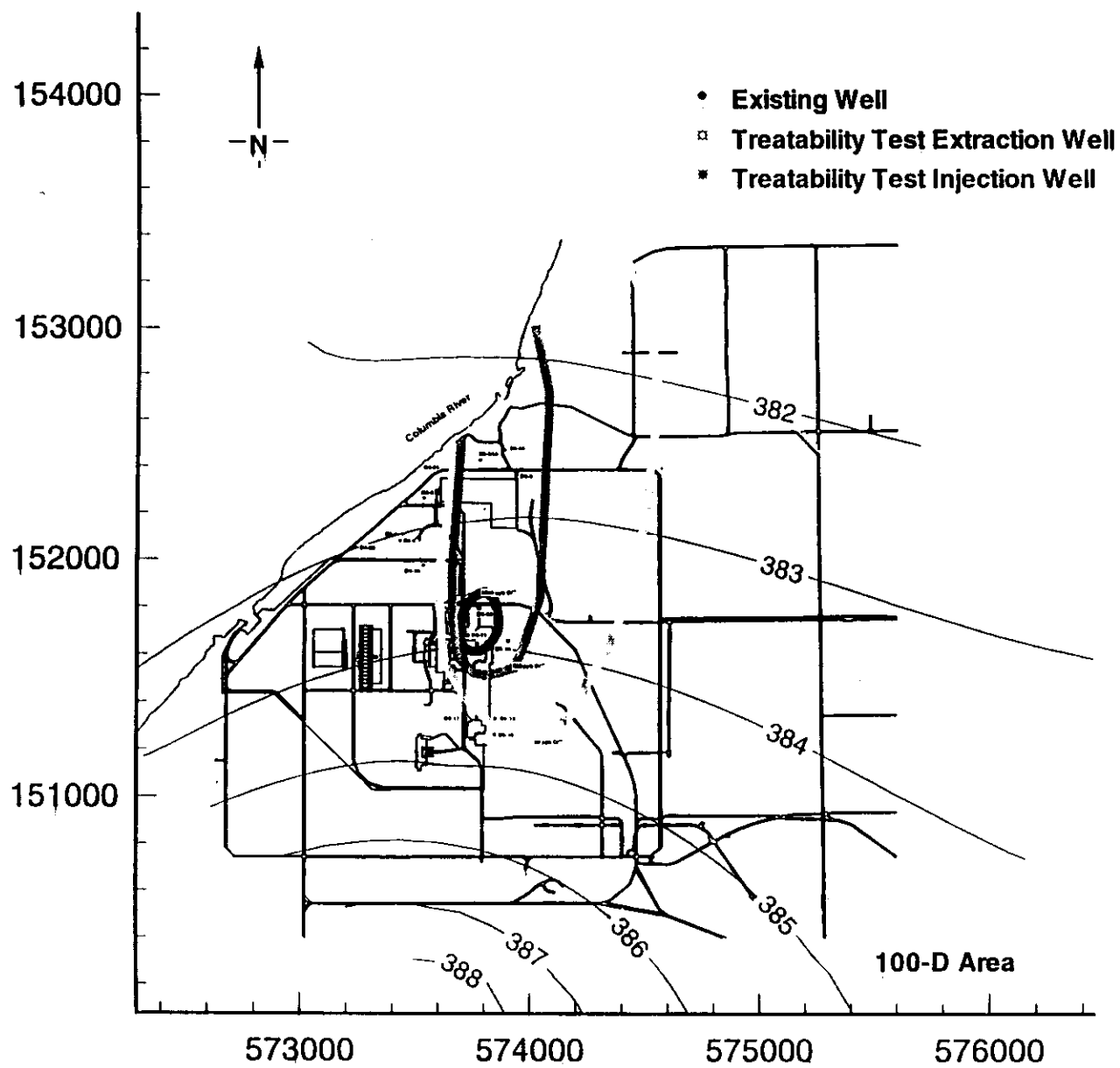


Figure 9. 100-KR-4 Transmissivity Distribution

To Be Generated.

Figure 10. 100-KR-4 Model Calibration Results

Comparison of Measured and Model Calibrated Hydraulic Head in 100-K.

Well ID	Average Hydraulic Head (m)	Model Calibrated Hydraulic Head (m)	Difference (m)
K-18	117.70	118.19	-0.49
K-19	118.30	118.33	-0.03
K-20	118.32	117.96	+0.36
K-21	117.80	117.86	-0.06
K-22	117.91	117.85	+0.06
K-32A	118.54	118.46	+0.08
K-33	118.06	118.51	-0.45
K-34	119.01	118.98	+0.03
K-35	120.43	120.05	+0.38
K-36	120.62	119.99	+0.63
K-37	118.10	117.85	+0.25
699-78-62	119.86	119.83	+0.03

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Figure 11. H Area Modeling Results

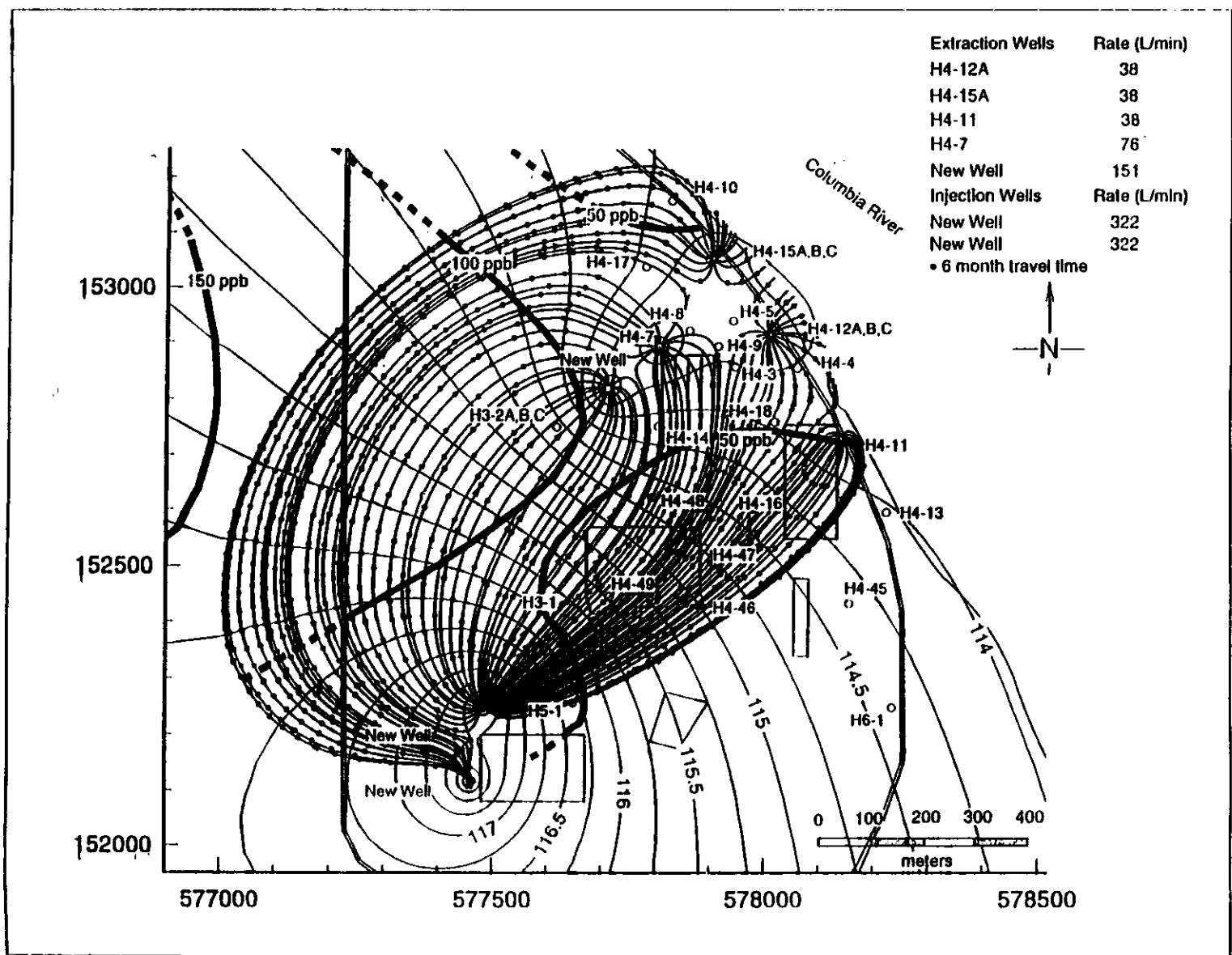


Figure 12. D Area Modeling Results

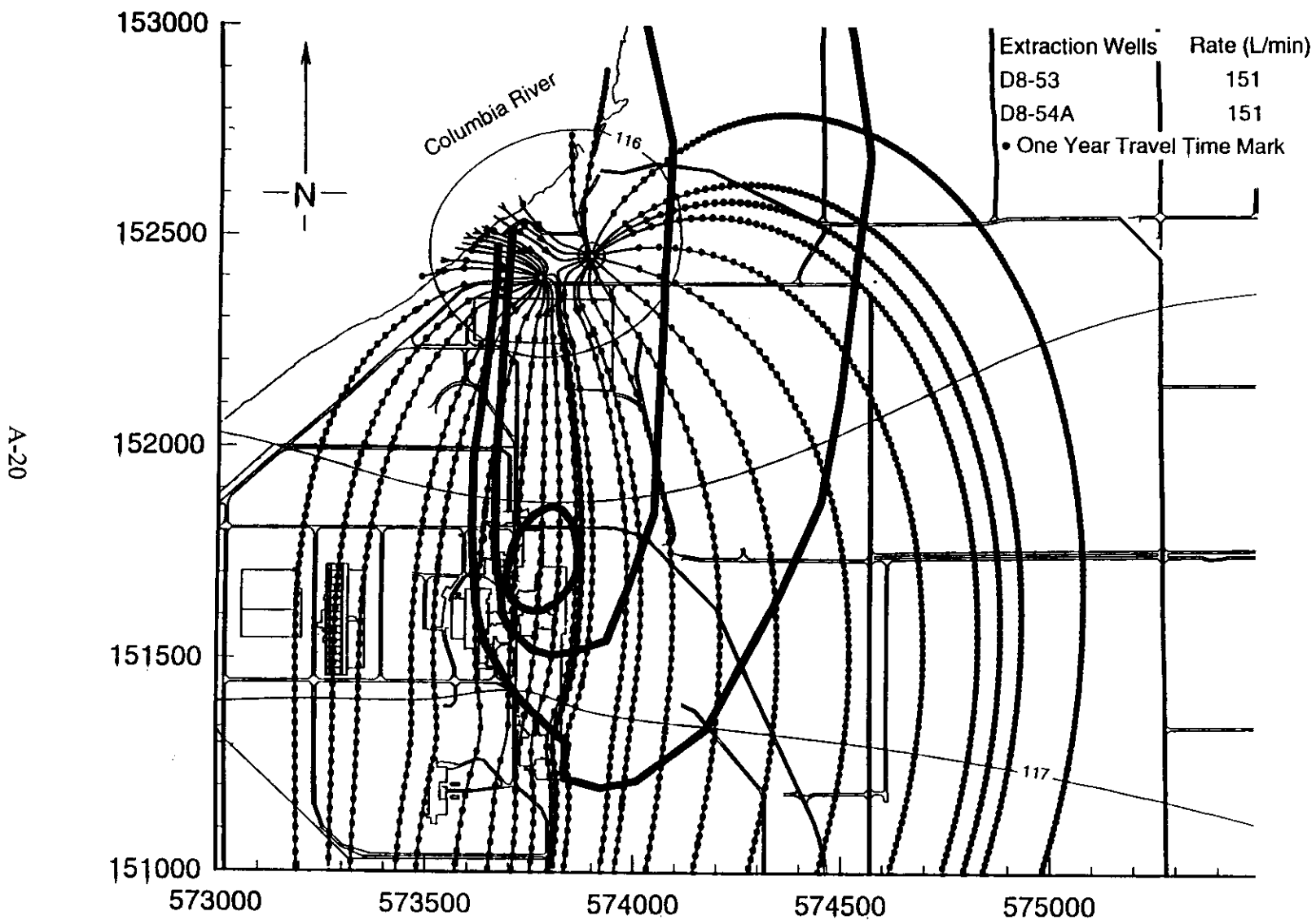


Figure 13. 100-KR-4 Modeling Results

